



US007737376B2

(12) **United States Patent**
Sydorenko et al.

(10) **Patent No.:** **US 7,737,376 B2**
(45) **Date of Patent:** **Jun. 15, 2010**

(54) **MECHANICAL SWITCH**

(75) Inventors: **Oleksandr Sydorenko**, Painted Post, NY (US); **Nikolai Zhitenev**, Berkeley Heights, NJ (US)

(73) Assignee: **Alcatel-Lucent USA Inc.**, Murray Hill, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 620 days.

(21) Appl. No.: **11/801,329**

(22) Filed: **May 9, 2007**

(65) **Prior Publication Data**

US 2008/0277252 A1 Nov. 13, 2008

(51) **Int. Cl.**
H01H 57/00 (2006.01)

(52) **U.S. Cl.** **200/181; 335/78**

(58) **Field of Classification Search** **200/181; 335/78**

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,372,820	B1	4/2002	Devonport	523/215
7,026,014	B2	4/2006	Luzinov et al.	427/402
7,049,904	B2 *	5/2006	Shin	333/105
7,052,616	B2 *	5/2006	Fonash et al.	216/2
7,125,938	B2	10/2006	Matyjaszewski et al.	526/147
2002/0100870	A1 *	8/2002	Whitehouse et al.	250/281
2003/0040173	A1 *	2/2003	Fonash et al.	438/622
2004/0180465	A1 *	9/2004	Musolf et al.	438/52
2005/0012562	A1 *	1/2005	Shin	333/105
2005/0032203	A1 *	2/2005	Beck et al.	435/287.2
2005/0242339	A1 *	11/2005	Beck	257/4
2006/0066423	A1 *	3/2006	Greywall et al.	335/78
2006/0094198	A1 *	5/2006	Klauk et al.	438/382
2006/0183262	A1 *	8/2006	Freidhoff	438/48
2007/0117244	A1 *	5/2007	Chen et al.	438/50

2007/0215866	A1 *	9/2007	Getty et al.	257/40
2008/0067555	A1 *	3/2008	Beebe et al.	257/212
2008/0079029	A1 *	4/2008	Williams	257/213
2008/0090337	A1 *	4/2008	Williams	438/133
2008/0179696	A1 *	7/2008	Chen et al.	257/415
2009/0136181	A1 *	5/2009	Vollmer et al.	385/50
2009/0242875	A1 *	10/2009	Zhitenev	257/40

FOREIGN PATENT DOCUMENTS

DE 10225313 A1 1/2004

(Continued)

OTHER PUBLICATIONS

U.S. Appl. No. 11/514,483, filed Sep. 1, 2006, Oleksandr Sydorenko et al.

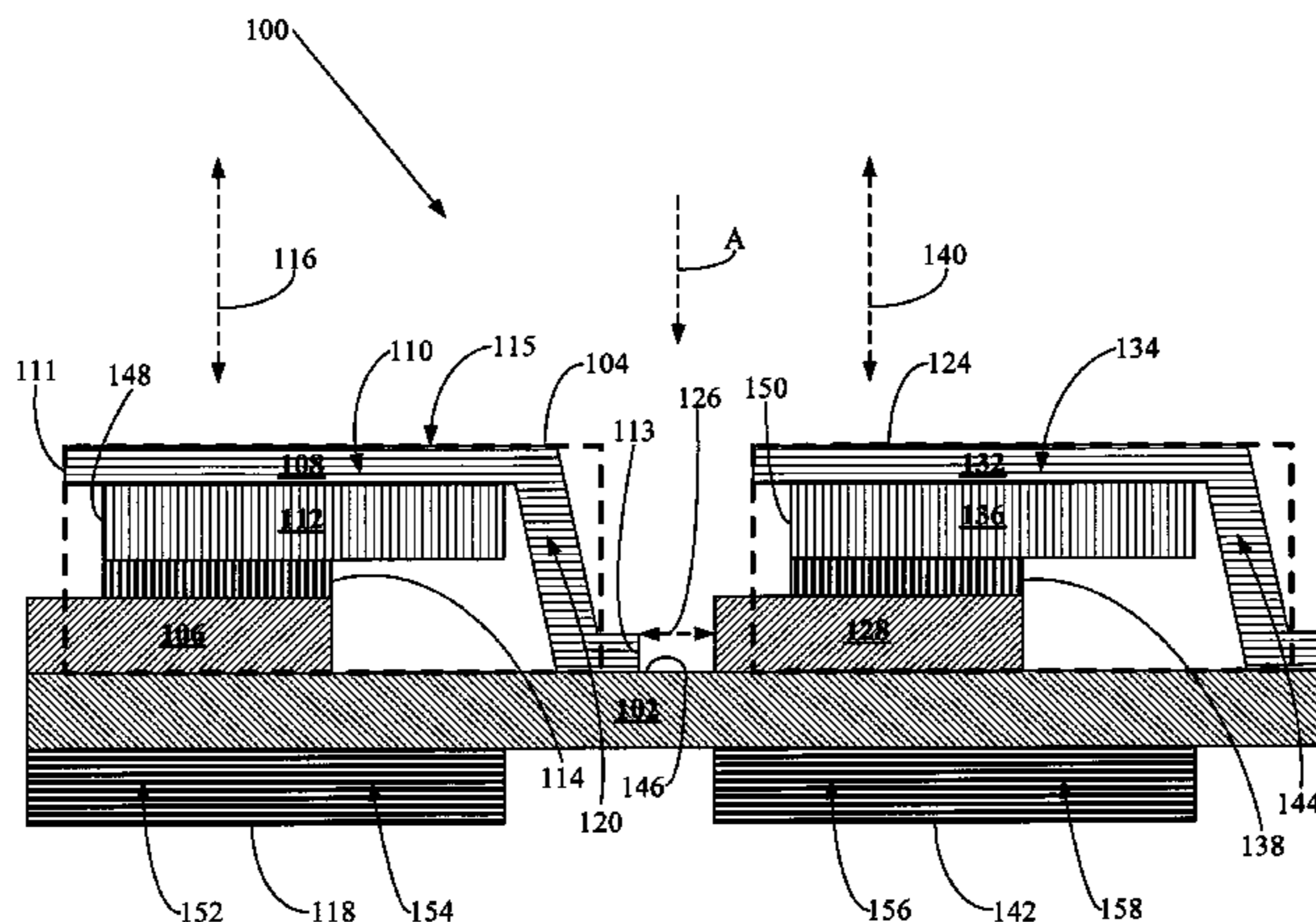
(Continued)

Primary Examiner—Michael A Friedhofer
(74) *Attorney, Agent, or Firm*—The Law Office of J.M. Brown

(57) **ABSTRACT**

Apparatus including a substrate and a mechanical switch, the mechanical switch located over the substrate, the mechanical switch including: a first electrical contact over the substrate; a support over the substrate, the support including a region moveable relative to the first electrical contact, the moveable region having a second electrical contact, the second electrical contact located over the first electrical contact; and a self-assembled molecular layer between the substrate and the second electrical contact. Method including placing into operation an apparatus, and applying a coulomb force causing the second electrical contact to move relative to the first electrical contact such that the switch is opened or closed.

20 Claims, 6 Drawing Sheets



FOREIGN PATENT DOCUMENTS

EP 1557396 A2 7/2005
WO WO03/101628 A1 12/2003

OTHER PUBLICATIONS

“Ordered Reactive Nanomembranes / Nanotemplates from Thin Films of Block Copolymer Supramolecular Assembly,” Oleksandr

Sydorenko, Igor Tokarev, Sergiy Minko, and Manfred Stamm, *J. Am. Chem. Soc.*, 125 (40), 12211-12216 (2003).

“Microphase Separation in Thin Films of Poly(styrene-block-4-vinylpyridine) Copolymer-2-(4'-Hydroxybenzeneazo)benzoic Acid Assembly,” Igor Tokarev, Radim Krenek, Yevgen Burkov, Dieter Schmeisser, Oleksander Sydorenko, Sergiy Minko, and Manfred Stamm, *Macromolecules*, 38 (2), 507-516 (2005); web release date Dec. 16, 2004.

* cited by examiner

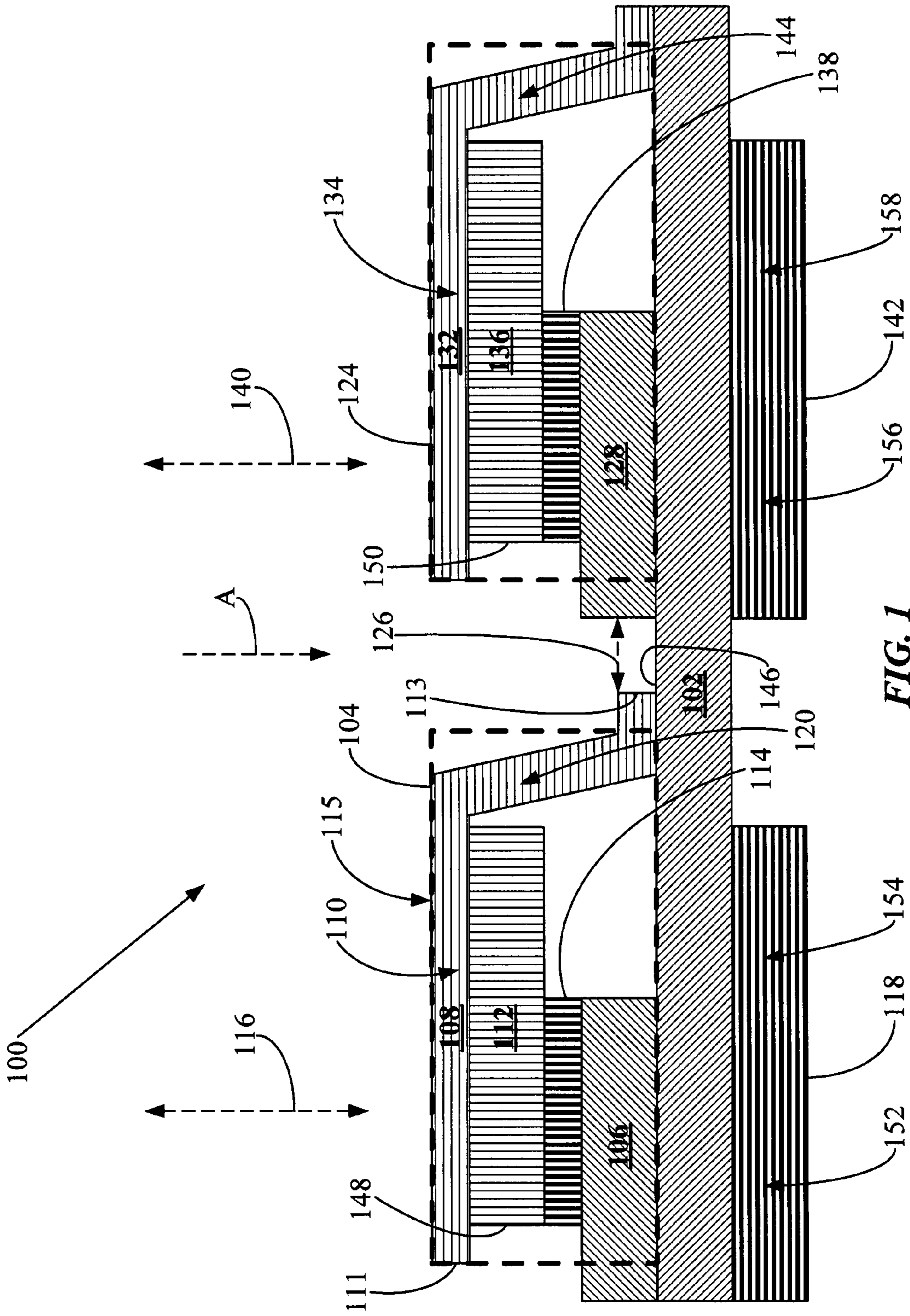


FIG. 1

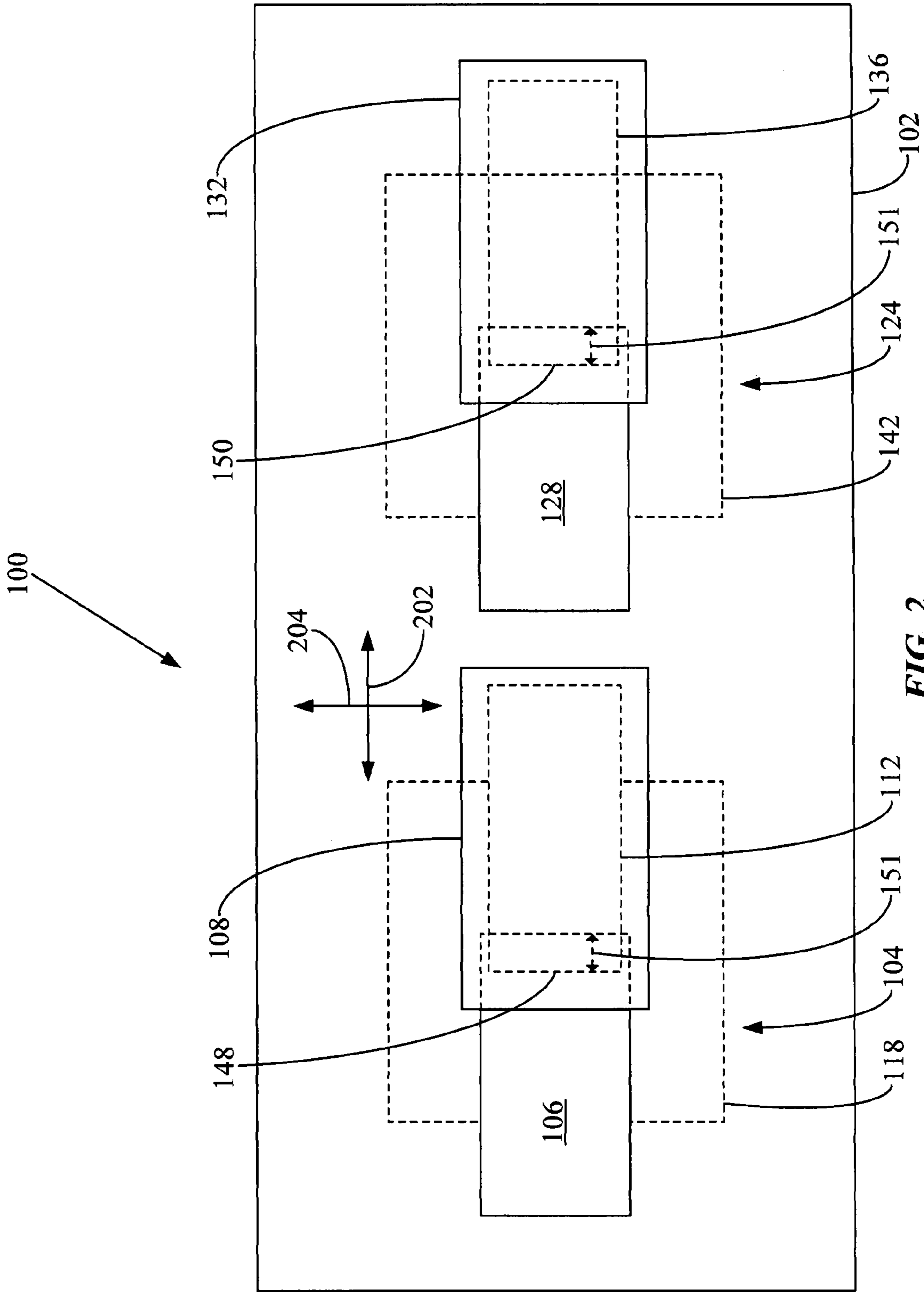


FIG. 2

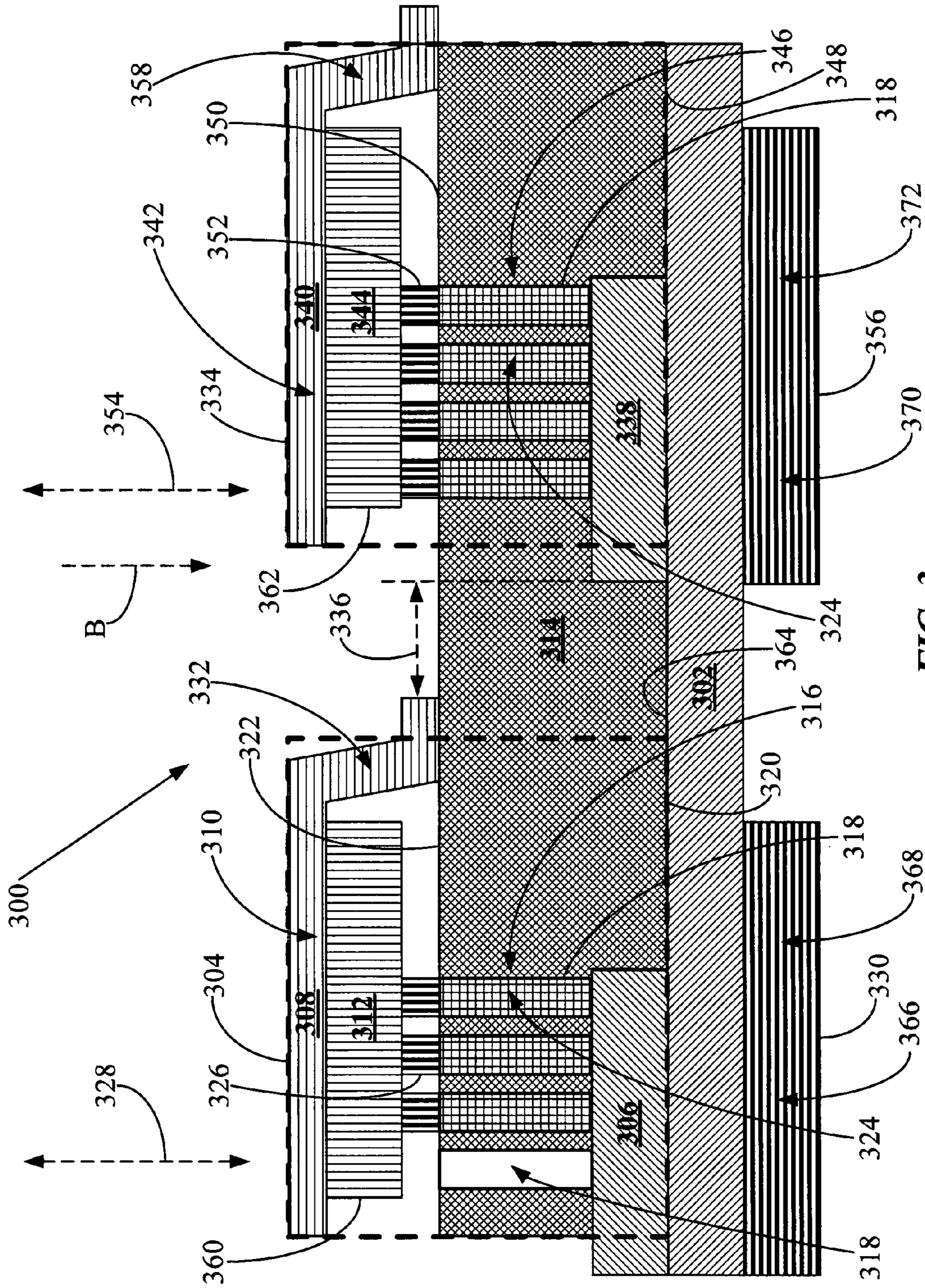


FIG. 3

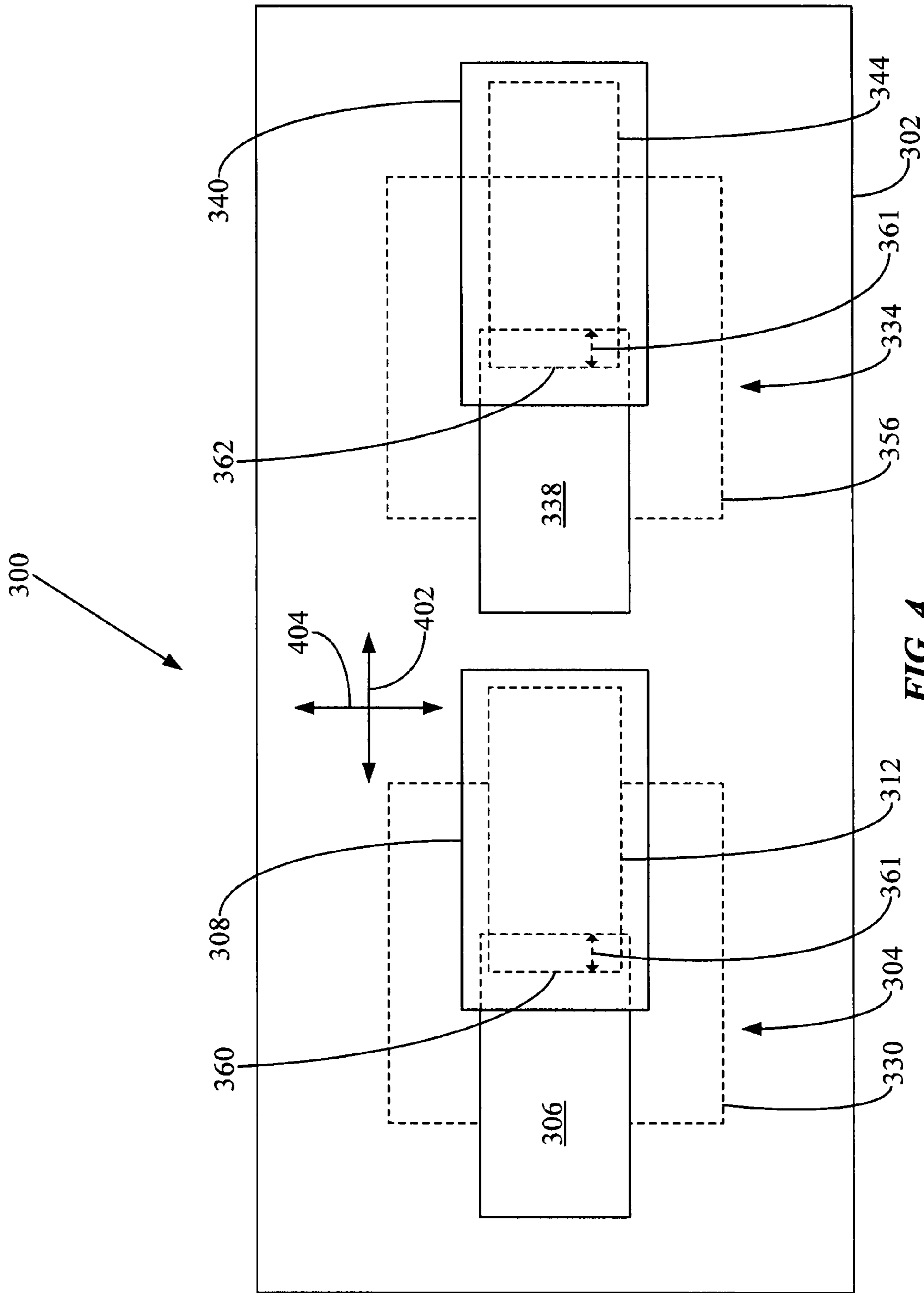


FIG. 4

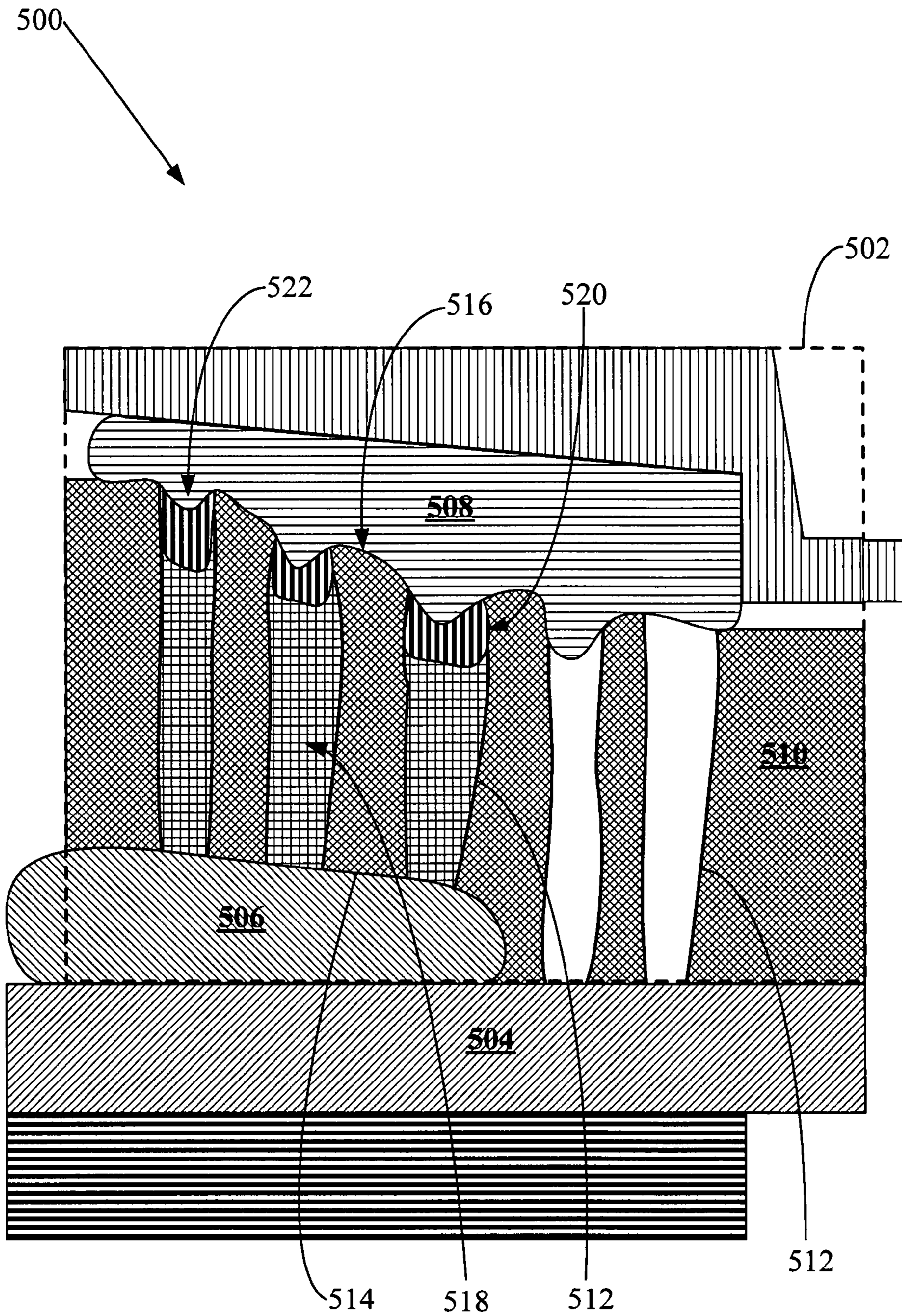
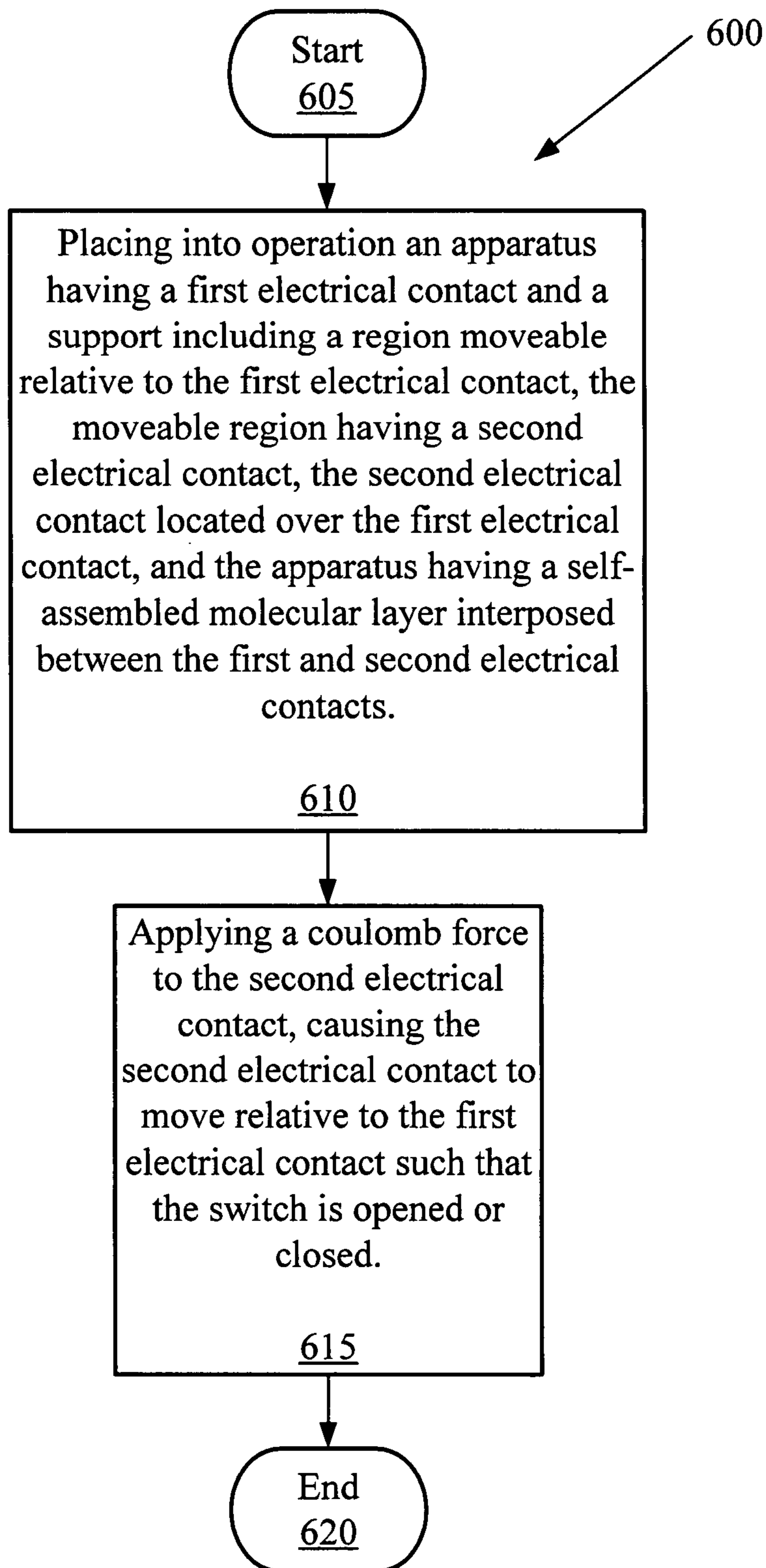


FIG. 5

**FIG. 6**

1

MECHANICAL SWITCH

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to mechanical switches and to methods for controlling a mechanical switch in an electrical circuit.

2. Related Art

Various types of mechanical switches have been developed. Further, myriad miniaturized electronic components have been developed for integration into an integrated circuit. There is a continuing need for miniaturized mechanical switches and for methods for controlling a mechanical switch in an electrical circuit.

SUMMARY

In an example of an implementation, an apparatus is provided that includes a substrate and a mechanical switch, the mechanical switch located over the substrate, the mechanical switch including: a first electrical contact over the substrate; a support over the substrate, the support including a region moveable relative to the first electrical contact, the moveable region having a second electrical contact, the second electrical contact located over the first electrical contact; and a self-assembled molecular layer between the substrate and the second electrical contact.

As another example of an implementation, a method is provided that includes placing into operation an apparatus having a first electrical contact and a support including a region moveable relative to the first electrical contact, the moveable region having a second electrical contact, the second electrical contact located over the first electrical contact, and the apparatus having a self-assembled molecular layer interposed between the first and second electrical contacts; and applying a coulomb force causing the second electrical contact to move relative to the first electrical contact such that the switch is opened or closed.

Other systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE FIGURES

The invention can be better understood with reference to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. 1 is a cross-sectional side view showing an example of an implementation of an apparatus.

FIG. 2 is a top view, taken in the direction of the arrow A, of the apparatus shown in FIG. 1.

FIG. 3 is a cross-sectional side view showing an example of another implementation of an apparatus.

FIG. 4 is a top view, taken in the direction of the arrow B, of the apparatus shown in FIG. 3.

FIG. 5 is a cross-sectional side view showing an example of part of an apparatus as shown in FIG. 3, including a mechanical switch.

2

FIG. 6 is a flow chart showing an example of an implementation of a method.

DETAILED DESCRIPTION

5

An apparatus is provided that includes a substrate and a mechanical switch. The mechanical switch is located over the substrate. The mechanical switch includes a first electrical contact over the substrate. The mechanical switch further includes a support over the substrate, the support including a region moveable relative to the first electrical contact. The moveable region has a second electrical contact. The second electrical contact is located over the first electrical contact. A self-assembled molecular layer is interposed between the first and second electrical contacts. The mechanical switch may, for example, include an electrical contact configured to apply a coulomb force capable of moving the second electrical contact relative to the first electrical contact such that the switch is opened or closed. In another example, the moveable region may locate the second electrical contact at a position spaced apart from the first electrical contact.

FIG. 1 is a cross-sectional side view showing an example of an implementation of an apparatus 100. The apparatus 100 includes a substrate 102, and a mechanical switch 104 indicated by a dotted line box. The mechanical switch 104 is located over the substrate 102. The mechanical switch 104 includes a first electrical contact 106 over the substrate 102. The mechanical switch 104 further includes a support 108 over the substrate 102, the support 108 including a region 110 moveable relative to the first electrical contact 106. As an example, the support 108 may include an arm as shown in FIG. 1. An arm may include first and second ends 111, 113 respectively, spaced apart by an elongated region 115. The moveable region 110 has a second electrical contact 112. The second electrical contact 112 is located over the first electrical contact 106. The mechanical switch 104 additionally includes a self-assembled molecular layer ("SAM") 114 interposed between the first and second electrical contacts 106 and 112. It is understood by those skilled in the art that a self-assembled molecular layer as referred to throughout this specification may include, fixed on a surface, a monolayer of molecules having two spaced-apart ends separated by an elongated region. Each molecule of the self-assembled molecular layer may have one of its ends chemically attached, e.g. covalently bonded, to the surface. Each molecule of the self-assembled molecular layer may have another of its ends unattached to the surface, leaving the elongated region and the unattached end free to move relative to other chemically fixed molecules of the self-assembled molecular layer, as by bending.

The first and second electrical contacts 106 and 112 may be, in an example, configured to together form a controllable electrical pathway in an electrical circuit (not shown). The moveable region 110 may be caused to move along a general direction of the arrow 116 relative to and toward the substrate 102. Upon sufficient displacement of the self-assembled molecular layer 114, an electrical connection may be completed such that the mechanical switch 104 is placed in a switch-closed state, closing an external circuit (not shown) of which the first and second electrical contacts 106 and 112 form a part of the electrical path. As another example, the apparatus 100 may include an electrical contact 118 configured to apply a coulomb force to the mechanical switch 104 capable of moving the second electrical contact 112 toward the first electrical contact 106 such that the switch is closed. Further according to such an example, the moveable region 110 of the mechanical switch 104 may locate the second

electrical contact **112** in a switch-open state at a position spaced apart from the first electrical contact **106**. In addition to the moveable region **110**, the support **108** of the mechanical switch **104** may include a flexible region **120**. The flexible region **120** of the support **108** may facilitate movement of the moveable region **110** along directions of the arrow **116**. It is understood that the location of the flexible region **120** shown in FIG. **1** is merely an example, and that an apparatus **100** may include one or more flexible regions (not shown) at other selected regions of the support **108**.

A device may be formed, for example, including two or more mechanical switches **104** on the substrate **102**. As an example, the apparatus **100** may include a second mechanical switch **124** indicated by a dotted line box, spaced apart at a lateral distance **126** from the mechanical switch **104**. The mechanical switch **104** may be referred to as the first mechanical switch. The second mechanical switch **124** may also be located over the substrate **102**. The second mechanical switch **124** includes a third electrical contact **128** over the substrate **102**. The second mechanical switch **124** further includes a second support **132** over the substrate **102**, the second support **132** including a second region **134** moveable relative to the third electrical contact **128**. As an example, the support **132** may include an arm as shown in FIG. **1**. The second moveable region **134** has a fourth electrical contact **136**. The fourth electrical contact **136** is located over the third electrical contact **128**. The second mechanical switch **124** additionally includes a self-assembled molecular layer **138** interposed between the third and fourth electrical contacts **128** and **136**. In another example, features of apparatus **300**, **500** discussed below in connection with FIGS. **3-4**, **5** may be included in the apparatus **100**. The entirety of the discussions below of apparatus **300**, **500** are incorporated in this discussion of the apparatus **100**.

The third and fourth electrical contacts **128** and **136** may be, in an example, configured to together form a controllable electrical pathway in an electrical circuit (not shown). The second moveable region **134** may be caused to move along a general direction of the arrow **140** relative to and toward the substrate **102**. Upon sufficient displacement of the self-assembled molecular layer **138**, an electrical connection may be completed such that the mechanical switch **124** is placed in a switch-closed state, closing an external circuit (not shown) of which the third and fourth electrical contacts **128**, **136** form part of the electrical path. As another example, the apparatus **100** may include an electrical contact **142** configured to apply a coulomb force to the second mechanical switch **124** capable of moving the fourth electrical contact **136** toward the third electrical contact **128** such that the switch is closed. Further according to such an example, the second moveable region **134** of the second mechanical switch **124** may locate the fourth electrical contact **136** in a switch-open state at a position spaced apart from the third electrical contact **128**. In addition to the second moveable region **134**, the second support **132** of the second mechanical switch **124** may include a second flexible region **144**. The second flexible region **144** of the second support **132** may facilitate movement of the second moveable region **134** along directions of the arrow **140**. It is understood that the location of the second moveable region **134** shown in FIG. **1** is merely an example, and that the second mechanical switch **124** may include one or more flexible regions (not shown) at other selected regions of the second support **132**.

An apparatus **100** including a plurality of mechanical switches **104**, **124** formed on the substrate **102** may, as examples, constitute part of an integrated circuit (not shown) or of a micro-electro-mechanical system (“MEMS”) (not

shown), or of a semiconductor device (not shown), or of a sensor (not shown), or of a filter (not shown), or of another electronic circuit (not shown). A MEMS may include mechanical elements, actuators for the mechanical elements, and electronics for controlling the actuators. A MEMS device may include sensors. A MEMS device may further include optical elements, such as mirrors controlled by the actuators. The term “semiconductor device” as used throughout this specification includes, as examples, transistors such as field effect transistors (“FETs”) and other types of transistors, diodes, and other semiconductor devices that may or may not utilize a doped semiconductor p-n hetero-junction between Group 3-5, 2-6, or 4-4 semiconductors allowing a controlled flow of electrons and/or holes across the hetero-junction.

As another example, a plurality of mechanical switches **104**, **124** may be formed in a laterally spaced-apart arrangement on the substrate **102**. The lateral spaced-apart arrangement may be, as examples, a uniform array or an arrangement forming parts of an integrated circuit, MEMS, semiconductor device, sensor, filter, or another electronic circuit. The lateral distance **126** between any two mechanical switches **104**, **124** may be determined consistent, for example, with a design for an integrated circuit, MEMS, semiconductor device, sensor, filter, or another electronic circuit, and may vary accordingly.

It is understood by those skilled in the art that the apparatus **100** as shown in FIG. **1** may be oriented in any direction. For example, upon orienting the apparatus **100** upside-down from its position shown in FIG. **1**, it is understood that the electrical contacts **106**, **112**, **128**, **136** and the supports **108**, **132** each remain “over” the substrate **102**. It is further understood that the electrical contacts **106**, **112**, **128**, **136** and the supports **108**, **132** each remain “over” the substrate **102** regardless of the interposition of additional elements of the apparatus **100** (not shown) between the substrate **102** and any or each of the electrical contacts **106**, **112**, **128**, **136** and the supports **108**, **132**.

FIG. **2** is a top view, taken in the direction of the arrow **A**, of the apparatus **100** shown in FIG. **1**. As an example, the apparatus **100** may include mechanical switches **104**, **124** over a substrate **102**. The mechanical switches **104**, **124** may respectively include supports **108**, **132**. The mechanical switch **104** may include first and second electrical contacts **106**, **112** located between the substrate **102** and the support **108**. The second mechanical switch **124** may include third and fourth electrical contacts **128**, **136** located between the substrate **102** and the support **132**. The mechanical switches **104**, **124** may, for example, respectively include electrical contacts **118**, **142**. The electrical contact **118** may include a contact part **152** aligned along directions of the arrow **116** with the first and second electrical contacts **106**, **112**; and a contact part **154** aligned along directions of the arrow **116** with only the second electrical contact **112**. The electrical contact **142** may include a contact part **156** aligned along directions of the arrow **140** with the third and fourth electrical contacts **128**, **136**; and a contact part **158** aligned along directions of the arrow **140** with only the fourth electrical contact **136**. The contact parts **154**, **158** may respectively facilitate application of a coulomb force to the second and fourth electrical contacts **112**, **136**. The contact parts **152**, **156** may be shielded by the first and third electrical contacts **106**, **128** from the second and fourth electrical contacts **112**, **136** along directions of the arrows **116**, **140**. Overall dimensions of each mechanical switch **104**, **124** in the directions of the arrows **202**, **204** may be selected to be sufficiently large to facilitate fabrication of the mechanical switches **104**, **124** and their connection into external circuits (not shown). Overall dimensions of each mechanical switch **104**, **124** in the directions of

the arrows **202**, **204** may be minimized so as to maximize a quantity of mechanical switches **104**, **124** that may be formed on a surface **146** of the substrate **102**. As examples, the dimensions of each mechanical switch **104**, **124** in the directions of the arrows **202**, **204** may be within ranges of between about 10 nanometers and about 2 microns. The supports **108**, **132** may, for example, be longer in the directions of the arrow **202** than the corresponding second electrical contact **112** and fourth electrical contact **136**. The relatively greater lengths of the supports **108**, **132** than the electrical contacts **112**, **136** in this example may facilitate flexing of the supports **108**, **132** in the directions of the arrows **116**, **140**.

As a further example, formation of an electrically-conductive connection between the first and second electrical contacts **106**, **112** and between the third and fourth electrical contacts **128**, **136** may be facilitated by positioning the second and fourth electrical contacts **112**, **136** to only partially overlap from a perspective taken in the directions of the arrows **116**, **140** with the first and third electrical contacts **106**, **128** along edges **148**, **150** of the second and fourth electrical contacts **112**, **136**, respectively. In an example, lengths of the edges **148**, **150** in the directions of the arrow **204** may be within a range of between about 10 nanometers and about 2 microns. As another example, a width **151** defined in the directions of the arrow **202** of a part of the second and fourth electrical contacts **112**, **136** that overlaps from a perspective taken in the directions of the arrows **116**, **140** with the first and third electrical contacts **106**, **128** respectively may be selected. The overlap width **151** may need to be adequately large to provide a low resistance pathway for a DC current between the first and second electrical contacts **106**, **112** when the mechanical switch **104** is closed. The overlap width **151** may also need to be adequately large to provide a low resistance pathway between the third and fourth electrical contacts **128**, **136** when the mechanical switch **124** is closed. The overlap width **151** may also be selected to avoid excessive overlap, to minimize potential electrical short circuiting between the respective electrical contacts through defects in the self-assembled molecular layer **114**, **138**. For example, a width **151** defined in directions of the arrow **202** of a part of the second and fourth electrical contacts **112**, **136** that overlap from a perspective taken in the directions of the arrows **116**, **140** with the first and third electrical contacts **106**, **128** respectively may be less than about one micron, or within a range of between about 100 nanometers and about 300 nanometers, or less than about 200 nanometers.

FIG. 3 is a cross-sectional side view showing an example of another implementation of an apparatus **300**. The apparatus **300** includes a substrate **302**, and a mechanical switch **304** indicated by a dotted line box. The mechanical switch **304** is located over the substrate **302**. The mechanical switch **304** includes a first electrical contact **306** over the substrate **302**. The mechanical switch **304** further includes a support **308** over the substrate **302**, the support **308** including a region **310** moveable relative to the first electrical contact **306**. As an example, the support **308** may include an arm as shown in FIG. 3. The moveable region **310** has a second electrical contact **312**. The second electrical contact **312** is located over the first electrical contact **306**. The apparatus **300** additionally includes a dielectric layer **314**. A part **316** of the dielectric layer **314** is interposed between the substrate **302** and the support **308**. The dielectric layer **314** has a hole **318** aligned between the first and second electrical contacts **306**, **312**. As an example, the dielectric layer **314** may have a first surface **320** facing the first electrical contact **306**, a second surface **322** facing the second electrical contact **312**, and a hole **318** between the first and second electrical contacts **306**, **312** and

communicating between the first and second surfaces **320**, **322**. In an example, the hole **318** may be a pore **318**. As a further example, the hole **318** may have an electrically-conductive filling **324**. An electrically-conductive filling **324** may include, for example, particles having a composition including one or more metals such as gold, silver, platinum, palladium, copper, nickel and chromium. In a further example, the electrically-conductive filling **324** may include, for example, particles having a composition including an electrically-conductive polymeric composition such as polythiophene, polyaniline, or poly(3,4-ethylenedioxy-thiophene):poly(styrenesulfonate), (also referred to as "PEDOT:PSS"). The mechanical switch **304** additionally includes a self-assembled molecular layer **326** interposed between the dielectric layer **314** and the second electrical contact **312**. As an example, the self-assembled molecular layer **326** may be located between the second electrical contact **312** and an electrically-conductive filling **324** in a pore **318**. In another example, features of apparatus **100** discussed above in connection with FIGS. 1-2 or of apparatus **500** discussed below in connection with FIG. 5 may be included in the apparatus **300**. The entireties of the discussions of apparatus **100**, **500** are incorporated in this discussion of the apparatus **300**.

The first and second electrical contacts **306** and **312** may be, in an example, configured to together form a controllable electrical pathway in an electrical circuit (not shown). The moveable region **310** may be caused to move along a general direction of the arrow **328** relative to and toward the substrate **302**. Upon sufficient displacement of the self-assembled molecular layer **326**, an electrical connection may be completed such that the mechanical switch **304** is placed in a switch-closed state, closing an external circuit (not shown) of which the first and second electrical contacts **306** and **312** form part of the electrical path. As another example, the apparatus **300** may include an electrical contact **330** configured to apply a coulomb force to the mechanical switch **304** capable of moving the second electrical contact **312** toward the first electrical contact **306** such that the switch is closed. Further according to such an example, the moveable region **310** of the mechanical switch **304** may locate the second electrical contact **312** in a switch-open state at a position spaced apart from the dielectric layer **314**. In addition to the moveable region **310**, the support **308** of the mechanical switch **304** may include a flexible region **332**. The flexible region **332** of the support **308** may facilitate movement of the moveable region **310** along directions of the arrow **328**. It is understood that the location of the flexible region **332** shown in FIG. 3 is merely an example, and that an apparatus **300** may include one or more flexible regions (not shown) at other selected regions of the support **308**.

An apparatus **300** may, for example, include a plurality of mechanical switches such as mechanical switch **304** on the substrate **302**. For example, a plurality of mechanical switches including the mechanical switch **304** and a second mechanical switch **334** may be located in a laterally spaced-apart arrangement on the substrate **302**. Such a plurality of mechanical switches **304**, **334** formed on the substrate **302** may, in examples, constitute components of an integrated circuit (not shown) or of a micro-electronic-mechanical system ("MEMS") (not shown), or of a semiconductor device (not shown), or of a sensor (not shown), or of a filter (not shown), or of another electronic circuit (not shown).

As an example, the apparatus **300** may include a second mechanical switch **334** indicated by a dotted line box, spaced apart at a lateral distance, indicated by the arrow **336**, from the mechanical switch **304**. The mechanical switch **304** may be referred to as the first mechanical switch. The second

mechanical switch **334** includes a third electrical contact **338** over the substrate **302**. The second mechanical switch **334** further includes a second support **340** over the substrate **302**, the second support **340** including a second region **342** moveable relative to the third electrical contact **338**. As an example, the support **340** may include an arm as shown in FIG. 3. The second moveable region **342** has a fourth electrical contact **344**. The fourth electrical contact **344** is located over the third electrical contact **338**. A part **346** of the dielectric layer **314** is interposed between the substrate **302** and the second support **340**. The dielectric layer **314** has a hole **318** aligned between the third and fourth electrical contacts **338**, **344**. As an example, the dielectric layer **314** may have a first surface **348** facing the third electrical contact **338**, a second surface **350** facing the fourth electrical contact **344**, and a hole **318** interposed between the third and fourth electrical contacts **338**, **344** and communicating between the first and second surfaces **348**, **350**. In an example, the hole **318** may be a pore **318**. As a further example, the hole **318** may have an electrically-conductive filling **324**. An electrically-conductive filling **324** may include, for example, particles having a composition including one or more metals such as gold, silver, platinum, palladium, copper, nickel and chromium; or a conductive polymeric composition as discussed earlier. The mechanical switch **334** additionally includes a self-assembled molecular layer **352** interposed between the dielectric layer **314** and the fourth electrical contact **344**. As an example, the self-assembled molecular layer **352** may be between the fourth electrical contact **344** and an electrically-conductive filling **324** in a pore **318**.

The third and fourth electrical contacts **338** and **344** may be, in an example, configured to together form a controllable electrical pathway in an electrical circuit (not shown). The second moveable region **342** may be caused to move along a general direction of the arrow **354** relative to and toward the substrate **302**. Upon sufficient displacement of the self-assembled molecular layer **352**, an electrical connection may be completed such that the mechanical switch **334** is placed in a switch-closed state, closing an external circuit (not shown) of which the third and fourth electrical contacts **338** and **344** form a part of the electrical path. As another example, the apparatus **300** may include an electrical contact **356** configured to apply a coulomb force to the second mechanical switch **334** capable of moving the fourth electrical contact **344** toward the third electrical contact **338** such that the switch is closed. Further according to such an example, the second moveable region **342** of the second mechanical switch **334** may locate the fourth electrical contact **344** in a switch-open state at a position spaced apart from the dielectric layer **314**. In addition to the moveable region **342**, the second support **340** of the second mechanical switch **334** may include a flexible region **358**. The flexible region **358** of the second support **340** may facilitate movement of the second moveable region **342** along directions of the arrow **354**. It is understood that the location of the flexible region **358** shown in FIG. 3 is merely an example, and that an apparatus **300** may include one or more flexible regions (not shown) at other selected regions of the second support **340**. As an example, the dielectric layer **314** may be flexible, to facilitate movement of the support **308**, **340** in directions of the arrows **328**, **354**.

It is understood by those skilled in the art that the apparatus **300** as shown in FIG. 3 may be oriented in any direction. For example, upon orienting the apparatus **300** upside-down from its position shown in FIG. 3, it is understood that the first, second, third and fourth electrical contacts **306**, **312**, **338** and **344**, and the support and second support **308**, **340**, each

remain "over" the substrate **302**. It is further understood that the first, second, third and fourth electrical contacts **306**, **312**, **338** and **344**, and the support and second support **308**, **340**, each remain "over" the substrate **302** regardless of the interposition of additional elements of the apparatus **300** (not shown) between the substrate **302** and any or each of the first, second, third and fourth electrical contacts **306**, **312**, **338** and **344**, and the support and second support **308**, **340**.

FIG. 4 is a top view, taken in the direction of the arrow B, of the apparatus **300** shown in FIG. 3. As an example, the apparatus **300** may include mechanical switches **304**, **334** over a substrate **302**. The mechanical switches **304**, **334** may respectively include supports **308**, **340**. The mechanical switch **304** may include first and second electrical contacts **306**, **312** located between the substrate **302** and the support **308**. The second mechanical switch **334** may include third and fourth electrical contacts **338**, **344** located between the substrate **302** and the second support **340**. The mechanical switches **304**, **334** may, for example, respectively include electrical contacts **330**, **356**. The electrical contact **330** may include a contact part **366** aligned along directions of the arrow **328** with the first and second electrical contacts **306**, **312**; and a contact part **368** aligned along directions of the arrow **328** with only the second electrical contact **312**. The electrical contact **356** may include a contact part **370** aligned along directions of the arrow **354** with the third and fourth electrical contacts **338**, **344**; and a contact part **372** aligned along directions of the arrow **354** with only the fourth electrical contact **344**. The contact parts **368**, **372** may respectively facilitate application of a coulomb force to the second and fourth electrical contacts **312**, **344**. The contact parts **366**, **370** may be shielded by the first and third electrical contacts **306**, **338** respectively from the second and fourth electrical contacts **312**, **344** along directions of the arrows **328**, **354**. Overall dimensions of each mechanical switch **304**, **334** in the directions of the arrows **402**, **404** may be selected to be sufficiently large to facilitate fabrication of the mechanical switches **304**, **334** and their connection into external circuits (not shown). Overall lateral linear dimensions of each mechanical switch **304**, **334** in the directions of the arrows **402**, **404** may be minimized so as to maximize a quantity of mechanical switches **304**, **334** that may be formed on the substrate **302**. As examples, the dimensions of each mechanical switch **304**, **334** in the directions of the arrows **402**, **404** may be within ranges of between about 10 nanometers and about 2 microns. The supports **308**, **340** may, for example, be longer in the directions of the arrow **402** than the corresponding second electrical contact **312** and fourth electrical contact **344**. The relatively greater lengths of the supports **308**, **340** than the electrical contacts **312**, **344** in this example may facilitate flexing of the supports **308**, **340** in the directions of the arrows **328**, **354**.

As a further example, formation of an electrically-conductive connection between the first and second electrical contacts **306**, **312** and between the third and fourth electrical contacts **338**, **344** may be facilitated by positioning the second and fourth electrical contacts **312**, **344** to only partially overlap from a perspective taken in the directions of the arrows **328**, **354** with the first and third electrical contacts **306**, **338** along edges **360**, **362** of the second and fourth electrical contacts **312**, **344**, respectively. In an example, lengths of the edges **360**, **362** in the directions of the arrow **404** may be within a range of between about 10 nanometers and about 2 microns. As another example, a width **361** defined in the directions of the arrow **402** of a part of the second and fourth electrical contacts **312**, **344** that overlaps from a perspective taken in the directions of the arrows **328**, **354** with the

first and third electrical contacts **306, 338** may be selected. The overlap width **361** may need to be adequately large to provide a low resistance pathway for electrical currents through the dielectric layer **314** between the first and second electrical contacts **306, 312** and between the third and fourth electrical contacts **338, 344**. The overlap width **361** may also be selected to avoid excessive overlap, to minimize potential electrical short circuiting between the respective electrical contacts through defects in the dielectric layer **314**. For example, a width **361** defined in the directions of the arrow **402** of a part of the second and fourth electrical contacts **312, 344** that overlap from a perspective taken in the directions of the arrows **328, 354** with the first and third electrical contacts **306, 338** may be less than about one micron, or within a range of between about 100 nanometers and about 300 nanometers, or less than about 200 nanometers.

In an example, the substrate **102, 302** may have a thickness in the directions of the arrows **116, 140, 328, 354** that is sufficiently large to provide structural integrity to the apparatus **100, 300** and that is not excessively large beyond a reasonable thickness needed for such integrity. For example, the substrate **102, 302** may have a thickness in the directions of the arrows **116, 140, 328, 354** within a range of between about 10 nanometers and about 500 nanometers. The electrical contacts **106, 112, 118, 128, 136, 142, 306, 312, 330, 338, 344, 356** may have thicknesses in the directions of the arrows **116, 140, 328, 354** that are sufficiently large to conduct an electrical current compatible with an external circuit (not shown), and that are not larger than may be needed to conduct such an electrical current. For example, the electrical contacts **106, 112, 118, 128, 136, 142, 306, 312, 330, 338, 344, 356** may have thicknesses in the directions of the arrows **116, 140, 328, 354** within a range of between about 5 nanometers and about 100 nanometers. The supports **108, 132, 308, 340** may have thicknesses in the directions of the arrows **116, 140, 328, 354** that are sufficiently large to provide structural integrity to the apparatus **100, 300** through repeated cycles of moving the moveable regions of the supports **108, 132, 308, 340** toward the electrical contacts **106, 128, 306, 338** without damage, and that are not so large as to prevent such repeated movement of the moveable regions of the supports **108, 132, 308, 340** toward the electrical contacts **106, 128, 306, 338**. For example, the supports **108, 132, 308, 340** may have thicknesses in the directions of the arrows **116, 140, 328, 354** within a range of between about 5 nanometers and about 50 nanometers.

The electrical contacts **106, 112, 118, 128, 136, 142, 306, 312, 330, 338, 344, 356** may be formed, as examples, from an electrically-conductive composition including one or more metals such as gold, silver, platinum, palladium, copper, nickel and chromium. In further examples, the electrical contacts **106, 112, 118, 128, 136, 142, 306, 312, 330, 338, 344, 356** may be formed from an electrically-conductive polymeric composition such as poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate), (also referred to as "PEDOT:PSS"). The substrates **102, 302** provide physical support to the apparatus **100, 300**. The substrates **102, 302** may include a crystalline semiconductor such as conventional p⁺-doped, n⁻-doped, or undoped crystalline silicon; or a conventional dielectric composition including a silica glass. The substrates **102, 302** may include multiple layers of dielectric and/or semiconductor materials. The supports **108, 132, 308, 340** may be formed, as examples, from a dielectric material. In further examples, the supports **108, 132, 308, 340** may be formed from a flexible dielectric material such as a polyester,

polyolefin, or polyamide. The supports **108, 132, 308, 340** may also be formed of an electrically-conductive composition.

The electrically-conductive filling **324** generally may be formed of any electrically-conductive composition capable of being selectively deposited into the holes **318**. As an example, the electrically-conductive filling **324** may include particles having a composition including a metal or a conductive polymer. For example, such particles may include nano-crystals formed of an electrically-conductive composition. The nano-crystals may be aggregated in clusters. As an example, the electrically-conductive filling **324** may protrude from the pores **318** in a direction along the arrows **328, 354** toward the second and fourth electrical contacts **312, 344**.

The self-assembled molecular layers **114, 138, 326, 352** may generally be formed from molecules suitable for forming an electrically non-conducting passivation layer. As an example, the self-assembled molecular layers **114, 138, 326, 352** may include molecules having two ends spaced apart by an elongated region, at least one end including a metal-reactive moiety. The molecules may, for example, include one or more thiol groups in mutually proximate or in mutually distant locations of the molecules. Thiol groups (—SH) may dissociate a hydrogen cation to yield a metal-reactive sulfur anion moiety. The self-assembled molecular layers **114, 138, 326, 352** may electrically insulate the electrical pathway between the first and second electrical contacts **106** and **112** or **306** and **312** and between the third and fourth electrical contacts **128** and **136** or **338** and **344** until the respective pairs of electrical contacts are brought closer together by displacing parts of the corresponding self-assembled molecular layers **114, 138, 326, 352**.

In an example, molecules for forming the self-assembled molecular layers **114, 138, 326, 352** may be selected having two ends spaced apart by an elongated region resulting in a selected overall molecular length. For example, molecules may be selected for forming the self-assembled molecular layers **114, 138, 326, 352** having an overall molecular length within a range of between about 0.5 nanometer and about 2 nanometers. Accordingly, a thickness of the resulting self-assembled molecular layers **114, 138, 326, 352** in directions of the corresponding arrows **116, 140, 328, 354** may likewise be within a range of between about 0.5 nanometer and about 2 nanometers. A self-assembled molecular layer **114, 138, 326, 352** having a thickness of at least about 0.5 nanometer in directions of the corresponding arrows **116, 140, 328, 354**, for example, may electrically insulate the first and third electrical contacts **106** and **128** from the second and fourth electrical contacts **112** and **136**, respectively, to minimize electrical conductivity through the switches **104, 124** in the switch-open state. Likewise, a self-assembled molecular layer **326, 352** having a thickness of at least about 0.5 nanometer in directions of the corresponding arrows **328, 354**, for example, may electrically insulate the first and third electrical contacts **306, 338** from the second and fourth electrical contacts **312, 344**, respectively, to minimize electrical conductivity through the switches **304, 334** in the switch-open state. For these reasons, the switches **104, 124, 304, 334** may not conduct a significant direct current ("DC") until the respective electrical contacts **106, 112, 128, 136, 306, 312, 338, 344** are brought closer together by deforming parts of the corresponding self-assembled molecular layers **114, 138, 326, 352**. A self-assembled molecular layer **114, 138, 326, 352** having a thickness of at least about 0.5 nanometer in directions of the corresponding arrows **116, 140, 328, 354** may also facilitate a function of interrupting the electrical connection between the first and second electrical contacts **106** and **112** or **306** and

312; or between the third and fourth electrical contacts 128 and 136 or 338 and 344. A self-assembled molecular layer 114, 138, 326, 352 having a thickness of greater than about 2 nanometers in directions of the arrows 116, 140, 328, 354 for example, may in some applications hinder formation of an electrical connection between the first and second electrical contacts 106 and 112 or 306 and 312; or between the third and fourth electrical contacts 128 and 136 or 338 and 344, by placing an excessive thickness of a self-assembled molecular layer 114, 138, 326, 352 between the respective electrical contacts that may not be adequately displaceable to result in current transmission.

The dielectric layer 314 may be formed of a composition suitable for making a flexible, deformable dielectric layer, to facilitate movement of the moveable regions 310, 342. As an example, a polymerizable composition suitable for forming a porous layer may be utilized. In a further example, the apparatus 300 may be selected to include a dielectric layer 314 having one or more pores 318 communicating with surfaces 320, 322, 348, 350 of the dielectric layer 314. For example, each of a plurality or matrix of such pores 318 may be utilized to form a plurality or matrix of mechanical switches 304, 334. In an example, the dielectric layer 314 may be formed with a thickness in the directions of the arrows 328, 354 sufficiently large to minimize current leakage through defects in the dielectric layer 314 between the first and second electrical contacts 306, 312 or between the third and fourth electrical contacts 338, 344. As another example, the dielectric layer 314 may be formed with a thickness in the directions of the arrows 328, 354 within a range of between about 5 nanometers and about 50 nanometers.

As examples, the dielectric layer 314 may be formed of a polymer composition selected as facilitating formation of pores 318. The polymer composition may, as an example, be a copolymer composition. In an example, the dielectric layer 314 may be fabricated by supramolecular assembly of a block copolymer ("BC"). Block copolymers may form well-ordered periodic nanostructures due to immiscibility of mutually unlike polymer blocks. The nanostructural morphology may depend on the volume ratio of the blocks, while the size of the features, which may be in a range of tens of nanometers, may be mostly influenced by the length of the blocks. Four typical morphologic patterns are observed for diblock copolymers in bulk: spherical (body-centered cubic), cylindrical (hexagonal), gyroidal (bicontinuous cubic), and lamellar, depending on the ratio of block lengths and segment-segment interaction parameters. For example, the periodicity may be within a range of between about 10 nanometers and about 100 nanometers.

In an example, the dielectric layer 314 may be fabricated from a supramolecular assembly of a block copolymer including poly(styrene-block-4-vinylpyridine) ("PS-PVP") and 2-(4'-hydroxybenzeneazo)benzoic acid ("HABA"). The dielectric layer 314 as initially formed from such a block copolymer may have one phase including cylindrical nanodomains formed by PVP associated with HABA, surrounded by another phase including poly(styrene) ("PS"). As further examples, poly(methyl methacrylate) or poly(butadiene) may be substituted for poly(styrene).

The preferential wetting of the substrate 302 by one of the phases in the system including PS-PVP and HABA drives the system to an alignment of the nanodomains parallel with the surface 364 of the substrate 302. In addition, the lowest surface tension component among the phases occupies the free surfaces 320, 322 of the dielectric layer 314, enhancing a trend toward this parallel alignment, which is parallel to the arrow 336.

When formed on the substrate 302, the block copolymer dielectric layer 314 may be capable of undergoing both surface relaxation and surface reconstruction. Surface phenomena may induce changes in the periodicity and may force one of the block phases to occupy the surfaces 320, 322 of the dielectric layer 314.

The dielectric layer 314 as initially formed may include cylindrical domains oriented in the directions of the arrow 336, parallel to the surfaces 320, 322 of the dielectric layer 314. The dielectric layer 314 may consist of parallel-oriented layers of the cylinders separated by a PS matrix and may have a fingerprint-like structure. The nanocylinders of PVP plus HABA may be packed into a distorted hexagonal lattice exhibiting 31 nanometers in-plane periodicity and 17 nanometers vertical periodicity in the directions of the arrows 328, 354. In both cases a thin wetting layer (not shown) may be found between the dielectric layer 314 and the substrate 302. The surfaces 320, 322 may be enriched with PS. Alignment of the cylindrical domains in the directions of the arrows 328, 354, perpendicular to the substrate surface 364, is in contradiction with a tendency of the domains to align parallel to the confining surfaces 320, 322 of the dielectric layer 314 due to preferential wetting of the interface between the dielectric layer 314 and the substrate 302 by one of the block phases.

Alignment of the domains may be switched from the perpendicular to parallel orientation and vice versa. Swelling of the dielectric layer 314 in 1,4-dioxane may lead the system to conversion from the cylindrical to the spherical morphology. Solvent evaporation may result in shrinkage of the copolymer in the perpendicular direction and subsequent merging of the spheres into the perpendicularly aligned cylinders. The cylinders may form a regular hexagonal lattice with a spatial period of 25.5 nanometers. Vapors of chloroform may induce in-plane alignment. Fast solvent evaporation may induce the perpendicular alignment of minor block cylinders with respect to the substrate surface 364, while slow evaporation may result in parallel alignment due to the preferential wetting.

Extraction of HABA with a selective solvent may result in a dielectric layer 314 having a hexagonal lattice (24 nanometers in the period) of holes 318 having a diameter of 8 nanometers crossing the dielectric layer 314 in directions of the arrows 328, 354. The walls of the holes 318 may include reactive PVP chains.

The block copolymer dielectric layer 314 may be annealed at a temperature above its glass-transition (T_g), resulting in the formation of a thermodynamically stable or metastable state and in an increase in lateral order. As another example, annealing of the dielectric film 314 in an external electric field of a high strength (at least 30 kilovolts per centimeter) may re-orient the domains perpendicular to the film surfaces.

As a further example, a minor component forming nanodomains may be eliminated to transform the block copolymer dielectric layer 314 into a layer having holes 318. Techniques including ultraviolet etching and plasma etching may be utilized. As another approach, 4-vinylpyridine (PVP) and 3-pentadecyl phenol monomers may be included in a polymerizable composition forming poly(styrene-block-4-vinylpyridine) (PS-PVP), into which the 4-vinylpyridine may be retained by hydrogen bonding. The supramolecular assembly of PVP and PDP may change the block copolymer morphology from spherical to cylindrical. The PDP may be removed by washing the copolymer with a selective solvent, providing nanoscopic holes 318 in the major component matrix.

Further background information on processes that may be utilized in formation of the dielectric layer 314 is disclosed in

“Ordered Reactive Nanomembranes/Nanotemplates from Thin Films of Block Copolymer Supramolecular Assembly,” Alexander Sydorenko, Igor Tokarev, Sergiy Minko, and Manfred Stamm, *J. Am. Chem. Soc.*, 125 (40), 12211-12216, 2003; and in “Microphase Separation in Thin Films of Poly (styrene-block-4-vinylpyridine) Copolymer-2-(4'-Hydroxybenzeneazo)benzoic Acid Assembly,” Igor Tokarev, Radim Krennek, Yevgen Burkov, Dieter Schmeisser, Alexander Sydorenko, Sergiy Minko, and Manfred Stamm, *Macromolecules*, 38 (2), 507-516, 2005; and in Australian Published Patent Application No. AU 2003239762 A1, filed May 26, 2003 and published Dec. 19, 2003, titled “Method for Producing Nanostructured Surfaces and Thin Films”, by Sergiy Minko, Manfred Stamm, Oleksandr Sydorenko, and Igor Tokarev, claiming priority of German patent application No. 102 25 313.7 filed Jun. 3, 2002; and related to PCT Published Patent Application No. WO 03/101628 A1 published Dec. 11, 2003, the entireties of all of which are incorporated into this specification by reference.

As another example, a pore-sized particle of a dry reagent having selective affinity for such a monomer or for another part of the polymer composition may be applied to the second surface 322, 350 and allowed to bore a pore 318 through the dielectric layer 314. In another example, the apparatus 300 may be selected to include a dielectric layer 314 that may be covalently bonded to a substrate 302.

The electrical contacts 106, 112, 118, 128, 136, 142, 306, 312, 330, 338, 344, 356 may be fabricated, as an example, by vapor deposition through shadow masks. Penetration of vapor such as metal vapor during formation of the electrical contacts 112, 136, 312, 344 into the respective self-assembled molecular layers 114, 138, 326, 352 may be dependent on a chemical composition of the selected vapor. Penetration of the selected vapor into the self-assembled molecular layers 114, 138, 326, 352 may be minimized by selecting molecules for forming the self-assembled molecular layers 114, 138, 326, 352 having two ends spaced apart by a relatively long elongated region, or by selecting molecules that pack relatively closely together forming a relatively dense structure that may minimize penetration of the vapor. Electrically-conducting fillings 324 may be filled into holes 318, for example, by electrochemical deposition. Self-assembled molecular layers 114, 138, 326, 352 may be formed, for example, by deposition of selected molecules from solution. Supports 108, 132, 308, 340 may be formed, for example, by vapor deposition and etching techniques.

FIG. 5 is a cross-sectional side view showing an example 500 of part of an apparatus 300 as shown in FIG. 3, including a mechanical switch 502 located over a substrate 504. The mechanical switch 502 includes a first electrical contact 506 over the substrate 504. The mechanical switch 502 further includes a second electrical contact 508. The second electrical contact 508 is located over the first electrical contact 506. The apparatus additionally includes a dielectric layer 510. The dielectric layer 510 has a plurality of holes 512 aligned between the first and second electrical contacts 506, 508. As an example, the dielectric layer 510 may have a first surface 514 facing the first electrical contact 506, a second surface 516 facing the second electrical contact 508, and a plurality of holes 512 interposed between the first and second electrical contacts 506, 508 and communicating between the first and second surfaces 514, 516. As examples, the holes may be pores 512. As a further example, a pore 512 may have an electrically-conductive filling 518. An electrically-conductive filling 518 may include, for example, particles having a composition including one or more metals or conductive polymeric compositions as discussed in connection with FIG.

3. The mechanical switch 502 additionally includes a self-assembled molecular layer 520 interposed between the first and second electrical contacts 506, 508. As an example, the self-assembled molecular layer 520 may be located in a pore 512, between the second electrical contact 508 and an electrically-conductive filling 518 also in the pore 512. The second electrical contact 508 may include, for example, bumps 522 partially intruding into pores 512 and making contact with a self-assembled molecular layer 520 in the pores 512.

As an example, the pores 512, electrically-conductive fillings 518, self-assembled molecular layers 520, and bumps 522 may be self-aligning during fabrication of the example of the apparatus 300. Such self-alignment may begin with formation, on the substrate 504, of the dielectric layer 510 including a pore 512 communicating between the first and second surfaces 514, 516. The electrically-conductive filling 518 may then be deposited from solution in the pore 512 by an electro-chemical technique. As an example, the electrically-conductive filling 518 may only partially fill the pore 512. The self-assembled molecular layer 520 may then be deposited from a solution dipping technique onto the electrically-conductive filling 518 in the pore 512. For example, thiol-terminated reagents for forming the self-assembled molecular layer 520 may be selectively bonded onto the electrically-conductive filling 518. The second electrical contact 508 including bumps 522 making contact with the self-assembled molecular layer 520 may then be formed over the dielectric layer 510 by shadow masking, vapor deposition, and etching techniques. The self-assembled molecular layer 520 may facilitate formation of the bumps 522 at locations spaced apart from the electrically-conductive filling 518 so that the mechanical switch 502 as fabricated is in a switch-open state. A density of molecules included in the self-assembled molecular layer 520 may be sufficiently high to minimize penetration into the self-assembled molecular layer 520 of vapor for formation of the second electrical contact 508. In another example, features of the apparatus 100 discussed above in connection with FIGS. 1-2 or of the apparatus 300 discussed above in connection with FIGS. 3-4 may be included in the apparatus 500. The entireties of the discussions above of the apparatus 100, 300 and of the materials and processes for fabrication of such apparatus are incorporated in this discussion of the apparatus 500.

FIG. 6 is a flow chart showing an example of an implementation of a method 600. The method starts at step 605, and at step 610 an apparatus is placed into operation having a first electrical contact and a support including a region moveable relative to the first electrical contact, the moveable region having a second electrical contact, the second electrical contact located over the first electrical contact, and the apparatus having a self-assembled molecular layer interposed between the first and second electrical contacts. In an example, the support may include an arm. The apparatus 100, 300, 500 discussed above, as examples, may be utilized. The entireties of the discussions above of the apparatus 100, 300, 500 in connection with FIGS. 1-5 are incorporated in this discussion of the method 600. Placing the apparatus into operation at step 610 may, for example, include fabricating the apparatus, or the apparatus may be pre-fabricated. In step 615, a coulomb force is applied to the second electrical contact, causing the second electrical contact to move relative to the first electrical contact such that the switch is opened or closed. The method 600 may then end at step 620.

In the following further examples, placing an apparatus into operation in step 610 may include placing into operation an apparatus having additional features; and step 615 may also be accordingly modified. Step 610 may include placing

15

into operation an apparatus having a moveable region locating the second electrical contact at a position spaced apart from the first electrical contact, and applying a coulomb force in step 615 may include causing the second electrical contact in the moveable region to move toward the first electrical contact. Also, step 610 may include placing into operation an apparatus having a self-assembled molecular layer including a molecule having two ends spaced apart by an elongated region, an end including a metal-reactive moiety. Step 610 may include placing into operation an apparatus having a third electrical contact and a second support including a second region moveable relative to the third electrical contact, the second moveable region having a fourth electrical contact, the fourth electrical contact located over the third electrical contact, and the apparatus having a self-assembled molecular layer interposed between the third and fourth electrical contacts. Additionally, step 610 may include placing into operation an apparatus having a dielectric layer, a part of the dielectric layer being interposed between the substrate and the support, the dielectric layer having a hole aligned between the first and second electrical contacts. Step 610 may, in addition, include placing into operation an apparatus having a dielectric layer including a first surface facing the first electrical contact, a second surface facing the second electrical contact, and a pore interposed between the first and second electrical contacts and communicating between the first and second surfaces. Placing an apparatus into operation in step 610 may also include utilizing an apparatus having a pore including an electrically-conductive filling. Further, step 610 may include placing into operation an apparatus having a pore including an electrically-conductive filling that includes particles having a composition including a metal.

The apparatus 100, 300, 500 may, for example, be utilized as components of an integrated circuit (not shown) or of a micro-electronic-mechanical system ("MEMS") (not shown), or of a semiconductor device (not shown), or of a sensor (not shown), or of a filter (not shown), or of another electronic circuit (not shown). As examples, "semiconductor devices" include transistors and diodes. Likewise, the method 600 may be utilized in diverse end-use applications for closing and interrupting current in an integrated circuit, MEMS, semiconductor device, sensor, filter, or other electronic circuit. While the foregoing description refers in some instances to the apparatus 100, 300, 500 and the method 600 as shown in FIGS. 1-6, it is appreciated that the subject matter is not limited to these structures, nor to the structures discussed in the specification. Other shapes and configurations of apparatus may be fabricated. Likewise, the method 600 may be performed utilizing any apparatus placed into operation in step 610, of which the apparatus 100, 300, 500 are examples. Further, it is understood by those skilled in the art that the method 600 may include additional steps and modifications of the indicated steps.

Moreover, it will be understood that the foregoing description of numerous examples has been presented for purposes of illustration and description. This description is not exhaustive and does not limit the claimed invention to the precise forms disclosed. Modifications and variations are possible in light of the above description or may be acquired from practicing the invention. The claims and their equivalents define the scope of the invention.

What is claimed is:

1. An apparatus comprising a substrate and a mechanical switch, the mechanical switch located over the substrate, the mechanical switch including:

a first electrical contact over the substrate;

16

a support over the substrate, the support including a region moveable relative to the first electrical contact, the moveable region having a second electrical contact, the second electrical contact located over the first electrical contact; and

a self-assembled molecular layer between the substrate and the second electrical contact.

2. The apparatus of claim 1, where the first and second electrical contacts are configured to together form a controllable electrical pathway in an electrical circuit.

3. The apparatus of claim 1, where the mechanical switch includes an electrical contact configured to apply a coulomb force capable of moving the second electrical contact relative to the first electrical contact, the relative movement capable of opening and closing the switch.

4. The apparatus of claim 1, where the support includes a flexible region.

5. The apparatus of claim 1, where the moveable region locates the second electrical contact at a position spaced apart from the first electrical contact in an open state of the mechanical switch.

6. The apparatus of claim 1, where the self-assembled molecular layer includes a plurality of molecules, each of a plurality of molecules having first and second ends spaced apart by an elongated region, an end including a metal-reactive moiety.

7. The apparatus of claim 1 including a second mechanical switch located over the substrate, the second mechanical switch including:

a third electrical contact over the substrate;

a second support over the substrate, the second support including a second region moveable relative to the third electrical contact, the second moveable region having a fourth electrical contact, the fourth electrical contact located over the third electrical contact; and

a self-assembled molecular layer interposed between the substrate and the fourth electrical contact.

8. The apparatus of claim 1, including a dielectric layer, a part of the dielectric layer interposed between the substrate and the support, the dielectric layer having a hole aligned between the first and second electrical contacts.

9. The apparatus of claim 8, where the dielectric layer has a first surface facing the first electrical contact, a second surface facing the second electrical contact, and a pore interposed between the first and second electrical contacts and communicating between the first and second surfaces.

10. The apparatus of claim 9, including a pore having an electrically-conductive filling.

11. The apparatus of claim 10, where the electrically-conductive filling includes particles having a composition including a metal.

12. The apparatus of claim 10, where the self-assembled molecular layer is interposed between the electrically-conductive filling and the fourth electrical contact.

13. A method comprising:

placing into operation an apparatus having a first electrical contact and a support including a region moveable relative to the first electrical contact, the moveable region having a second electrical contact, the second electrical contact located over the first electrical contact, and the apparatus having a self-assembled molecular layer interposed between the first and second electrical contacts; and

applying a coulomb force causing the second electrical contact to move relative to the first electrical contact such that the switch is opened or closed.

17

14. The method of claim 13, where placing an apparatus into operation includes utilizing an apparatus having a moveable region locating the second electrical contact at a position spaced apart from the first electrical contact, and where applying a coulomb force includes causing the second electrical contact in the moveable region to move toward the first electrical contact such that the switch is closed.

15. The method of claim 13, where placing an apparatus into operation includes utilizing an apparatus having a self-assembled molecular layer including a molecule having two ends spaced apart by an elongated region, an end including a metal-reactive moiety.

16. The method of claim 13, where placing an apparatus into operation includes utilizing an apparatus having a third electrical contact and a second support including a second region moveable relative to the third electrical contact, the second moveable region having a fourth electrical contact, the fourth electrical contact located over the third electrical contact, and the apparatus having a self-assembled molecular layer interposed between the third and fourth electrical contacts.

18

17. The method of claim 13, where placing an apparatus into operation includes utilizing an apparatus having a dielectric layer, a part of the dielectric layer being interposed between the substrate and the support, the dielectric layer having a hole aligned between the first and second electrical contacts.

18. The method of claim 17, where placing an apparatus into operation includes utilizing an apparatus having a dielectric layer including a first surface facing the first electrical contact, a second surface facing the second electrical contact, and a pore interposed between the first and second electrical contacts and communicating between the first and second surfaces.

19. The method of claim 18, where placing an apparatus into operation includes utilizing an apparatus having a pore including an electrically-conductive filling.

20. The method of claim 19, where placing an apparatus into operation includes utilizing an apparatus having a pore including an electrically-conductive filling that includes particles having a composition including a metal.

* * * * *